



Impact of dietary enzyme complex on growth performance, nutrient digestibility and fecal noxious gas emissions in growing pigs

P Y ZHAO¹, T S LI² and I H KIM³

Dankook University, Cheonan, Chungnam 31116 South Korea

Received: 30 November 2015; Accepted: 1 April 2016

ABSTRACT

Growing pigs (180, Yorkshire-Landrace × Duroc) with an average body weight (BW) of 26.40 ± 2.29 kg were used in a 6-week study to evaluate the effect of dietary enzyme complex on growth performance, nutrient digestibility, and fecal noxious gas emission in growing pigs. Pigs were sorted by their initial BW and sex, and allotted to pen given a basal diet with 0, 0.05 and 0.10% enzyme complex. Overall (d 0 to 36), pigs fed the enzyme complex supplementation diets had a greater apparent total tract digestibility (ATTD) of dry matter (DM) and nitrogen (N) than pigs fed the basal diet (CON). Fecal ammonia, hydrogen sulfide, total mercaptans, and acetic acid emissions were not affected by the enzyme complex supplementation on d 1, 3, 5, and 7. No effects were observed on growth performance, nutrient digestibility, and fecal noxious gas emissions between the enzyme complex supplementation treatments. In conclusion, enzyme complex supplementation in corn-soybean based diets improved the ATTD of DM and N, but neither improved growth performance nor decreased fecal noxious gas emissions in growing pigs.

Key words: Enzyme complex, Fecal noxious gas emission, Growth performance, Growing pigs, Nutrient digestibility

Pigs cannot digest 15–25% of the feed they eat, because the feed ingredients contain anti-nutritional factors that interfere with the digestive process and/or pig lack enzymes to digest some nutrients in the feed. Anti-nutritional factors can reduce protein digestibility, bind to various nutrients or damage the gut wall and thereby reduce digestive efficiency. In the 1950s, scientists added enzymes (amylases and proteases) to diets of various farm animals and observed benefits in productivity. Since then, use of exogenous feed enzymes has been one of the most widely studied issues in the animal industry (Adeola and Cowieson 2011). Enzymes act on the anti-nutritional factors and breakdown nutrients that are not digested by animals. Omogbenigun *et al.* (2004) supplemented an enzyme mixture (cellulase, galactanase, mannanase and pectinase) in wheat-based diet observed an improvement in growth performance of weanling pigs. Additionally, feeding weanling pigs (15 kg) with diets containing xylanase and wheat co-products improved ileal and total tract apparent digestibility of dry matter (DM), crude protein (CP) and energy (Yin *et al.* 2000). While, Kim *et al.* (1998) reported that finishing pigs fed sorghum-based diets containing 0.05% cellulase did not affect growth performance, carcass characteristics and nutrient utilization. The use of enzyme (amylase and cellulase) in sorghum-

based diets did not substantially improve growth performance and nutrient utilization in finishing pigs (Park *et al.* 2003). As most of previous studies focused on effects of enzyme complex in weanling and finishing pigs, meanwhile, inconsistent effects were observed. We want to evaluate the effect of enzyme complex in corn-soybean diets on growth performance, nutrient digestibility, and fecal noxious gas emission in growing pigs.

MATERIALS AND METHODS

Enzyme complex: The enzyme complex was obtained from a commercial company. It contains cellulase (12,000 units/g), amylase (10,000 units/g), protease (2,000 units/g), xylanase (1,500 units/g), phytase (1,000 units/g), β -glucanase (125 units/g), mannanase (30 units/g), pectinase (20 units/g), lipase (5 units/g) and galactosidase (3 units/g).

Experimental design, animals and housing: The experimental protocol used in this study was approved by the Animal Care and Use Committee of Dankook University. Growing pigs (180, Yorkshire = Landrace × Duroc) with an average body weight (BW) of 26.40 ± 2.29 kg were used in a 6 week experiment. Pigs were allotted to 3 experimental diets based on their initial BW and sex (10 replicate pens/treatment; 3 gilts and 3 barrows/pen). Dietary treatment groups were: (1) CON, basal diet, (2) CON + 0.05% enzyme complex (EC1), (3) CON + 0.10% enzyme complex (EC2). The diets were formulated to meet or

Present address: ^{1,2}Ph.D. Research Fellow (zhaopinyao@hotmail.com, leechensoo@163.com), ³Professor (inhokim@dankook.ac.kr).

Table 1. Composition of growing pig diets (as-fed basis) ¹

Item	Content
<i>Ingredient, g/kg</i>	
Ground corn	588.9
Soybean meal, 475 g crude protein/kg	320.8
Tallow	28.0
Molasses	30
Limestone	3.6
Monocalcium phosphate	18.4
Salt	1.5
L-Lysine-HCl, 780 g/kg	2.7
DL-Methionine, 500 g/kg	1
L-Threonine, 890 g/kg	0.7
Choline chloride, 250 g/kg	1.1
Vitamin premix ²	1.3
Trace mineral premix ³	2
<i>Calculated composition, g/kg</i>	
Metabolizable energy, kcal/kg	3537
Crude protein	176.6
Calcium	7.0
Total phosphorus	6.3
Lysine	10.1
Methionine + cysteine	9.3
Neutral detergent fiber	83.6
Acid detergent fiber	37.6
<i>Analyzed composition, g/kg</i>	
Crude protein	174.3
Calcium	7.8
Total phosphorus	6.1
Lysine	10.8
Methionine + cysteine	9.8
Neutral detergent fiber	83.8
Acid detergent fiber	37.2

¹CON, basal diet; EC1, basal diet + 0.5 g/kg enzyme complex; and EC2, basal diet + 1.0 g/kg enzyme complex; ²Provided per kg of complete diet: vitamin A, 4,000 IU; vitamin D₃, 800 IU; vitamin E, 171 IU; vitamin K, 2 mg; riboflavin, 4 mg; niacin, 20 mg; thiamine, 4 mg; d-pantothenic, 11 mg; choline, 166 mg; biotin, 0.08 mg; and vitamin B₁₂, 16 µg; ³Provided per kg of complete diet: Cu (CuSO₄·5H₂O), 15 mg; Fe (FeSO₄·7H₂O), 80 mg; Zn (ZnSO₄), 56 mg; Mn (MnO₂), 74 mg; I (as KI), 0.3 mg; Co (CoSO₄·5H₂O), 0.5 mg; and Se (Na₂SeO₃·5H₂O), 0.4 mg.

exceed all nutrient requirements (NRC 2012) (Table 1). Pigs were housed in an environmentally controlled, slatted plastic floor facility in 30 adjacent pens. Each pen was equipped with a self-feeder and nipple drinker to allow *ad lib.* access to feed and water throughout the experimental period.

Sampling and measurements: Pig BW and feed consumption were recorded at the end of week 6 to calculate average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F). Pigs were fed diets mixed with chromic oxide (0.2%) as an indigestible marker for the determination of apparent total tract digestibility (ATTD) for DM and nitrogen (N) (Fenton and Fenton 1979) for 7 d prior to fecal collection during the last week of the experiment. On d 42, fecal samples were collected randomly from 2 pigs (1 gilt and 1 barrow) in each pen via rectal

massage, and the urine was collected in a bucket via a funnel below the cage.

For nutrients and digestibility analysis, all feed and fecal samples were stored at -20°C until analysis. Before chemical analysis, fecal samples were thawed at 57°C for 72 h, after which they were ground to pass through a 1-mm screen. All feed and fecal samples were analyzed for DM (method 930.15; AOAC International 2007) and CP (method 990.03; AOAC International 2007). Chromium was analyzed via UV absorption spectrophotometry. The ATTD was then calculated using the following formula:

$$\text{Digestibility (\%)} = \{1 - [(Nf \times Cd)/(Nd \times Cf)]\} \times 100$$

Where, Nf, nutrient concentration in feces (% DM); Nd, nutrient concentration in diet (% DM); Cd, chromium concentration in diet (% DM); and Cf, chromium concentration in feces (% DM).

For analysis of fecal gas emission, subsamples of slurry (150 g fresh feces and 150 g urine from the same pen were mixed well; 1:1 on the wet weight basis) were taken and stored in 2.6-L plastic boxes in duplicate (Zhao *et al.* 2013a). Each box had a small hole in the middle of one side wall, which was sealed with adhesive plaster. The samples were permitted to ferment for 1 d at room temperature (25°C), after which the adhesive plasters were punctured, and 100 ml of headspace air was sampled approximately 2.0 cm above the slurry surface. Two samples from each pen were measured and then the average was calculated. A gas sampling pump was utilized for gas (ammonia, hydrogen sulfide and acetic acid) detection. After collection, the boxes were resealed with adhesive plaster to measure the fecal gas content at d 3, 5, and 7 as afore mentioned. Prior to the measurements, slurry samples were shaken manually for approximately 30 sec to disrupt any crust formation on the surface of the slurry sample and to homogenize them.

Statistical analysis: All experimental data were analyzed as a randomized complete block design using the GLM procedures. The pen was used as the experimental unit. Orthogonal contrasts were used to the effect of treatments: CON vs. EC1 + EC2 and EC1 vs. EC2. Variability in the data was expressed as the pooled standard error of mean (SEM), and P<0.05 was considered statistically significant.

RESULTS AND DISCUSSION

Growth performance: Pigs cannot degrade non-starch polysaccharide (NSP) efficiently found in corn and soybean meal as lack necessary enzymes to digest NSP, and rely largely upon anaerobic bacteria in large and small intestines (Grieshop *et al.* 2001). Beneficial effects of addition of enzymes such as β-mannanase, amylase, protease and xylanase to diets fed to weanling and growing-finishing pigs were reported (Petty *et al.* 2002, Yi *et al.* 2013). Jo *et al.* (2012) demonstrated that supplementation of 0.05% of α-amylase, β-mannanase, and protease complex enzymes to a corn-soybean meal diet may improve the growth performance of growing pigs. However, in the present study, ADG, ADFI, and G:F were not affected in growing pigs fed corn-soybean diets with 0.05 or 0.10% enzyme complex.

Table 2. Effect of dietary enzyme complex supplementation on growth performance and apparent total tract digestibility of DM, N, and gross energy in growing pigs^{1,2,3}

Item	Treatment			SEM	P-value	
	CON	EC1	EC2		CON vs. EC1 + EC2	EC1 vs. EC2
Growth performance						
ADG (g)	676	710	713	17	0.103	0.898
ADFI (g)	1,546	1,575	1,563	25	0.455	0.742
G:F	0.438	0.451	0.457	0.013	0.303	0.720
Digestibility (%)						
DM	75.72	76.77	77.17	0.47	0.042	0.549
N	69.49	72.57	71.77	0.65	0.003	0.389
GE	75.86	76.73	77.79	0.57	0.056	0.199

¹CON, basal diet; EC1, basal diet + 0.5 g/kg enzyme complex; and EC2, basal diet + 1.0 g/kg enzyme complex, ²Each mean represents 10 pens with 6 pigs (initial BW, 26.40 ± 2.29 kg) per pen, ³ADG, average daily gain; ADFI, average daily feed intake; G:F, gain: feed; DM, dry matter; N, nitrogen; GE, gross energy; SEM, standard error of mean.

The different results may be due to supplementation of different enzymes. Yoon *et al.* (2010) reported that adding mannanase to corn-soybean meal-based diets containing 10 and 15% DDGS may improve ADG, ADFI, and G:F in growing-finishing pigs. Wang *et al.* (2008) also reported that ADG and G:F in growing pigs fed the rough rice based diet supplemented with 2 g/kg enzymes (xylanase, β -glucanase and cellulase) were improved compared to the control group. No improvement in ADG, ADFI, and G:F was observed when growing-finishing pigs were fed hullless barley diets supplemented with multienzyme preparations (β -glucanase, pentosanase, cellulase, amylase and pectinase) (Thacker *et al.* 1988), and finishing pigs were fed sorghum-soy diet containing cellulase (Kim *et al.* 1998). The inconsistent results of those experiments may be caused by the different source of diets and different enzymes. Weanling pigs fed corn-soybean meal- and wheat-soybean meal-based diets supplemented with enzyme (cellulase, galactanase, mannanase and pectinase) had higher ADG and G:F than those fed the control diet (Omogbenigun *et al.* 2004). Taken together, the different results in growth performance among previous studies mentioned above are mainly attributable to different growth phase of pigs, composition of diets, enzyme dose, and amount of substrate in the basal diet.

Nutrient digestibility: Digestive capacity in pigs improves with age as the mature enzyme system and increased gut microbial population (Lindemann *et al.* 1986). The apparent ileal digestibility and ATTD of DM, GE, and CP were increased in enzyme supplementation (cellulase, galactanase, mannanase and pectinase) treatments fed the corn-soybean meal diet or wheat-soybean meal diet in weanling pigs (Omogbenigun *et al.* 2004). Wang *et al.* (2004) reported that supplementation of exogenous enzymes (β -glucanase, xylanase, and cellulase) increased the ATTD of CP, CF, and crude fat in growing pigs fed a paddy-based diet. Moreover, multienzyme supplementation (xylanase, β -glucanase and cellulase) of 30% wheat distillers dried grains with solubles-based diets improved the apparent ileal digestibility of DM and GE in finishing pigs and ATTD of

DM, N, and GE in growing pigs (Emiola *et al.* 2009). Consistent with our study, the ATTD of DM and N was greater in pigs fed the enzyme complex supplemented corn-soybean diet (P=0.042 and 0.003, respectively) compared with pigs fed the CON diet (Table 2). No effect was observed for ATTD of GE. There was no difference in growth performance and ATTD of DM, N or GE between the levels of enzyme complex supplementation (0.05 or 0.10%). Kim *et al.* (1998) reported that finishing pigs fed corn-soybean meal diet had a greater ATTD of DM, N and GE than pigs fed the sorghum-soybean meal diet. Li *et al.* (1993) also demonstrated that the ATTD of CP and GE in weanling pigs fed wheat, corn, and rye-based diets supplemented with cellulase were not affected; however, when cellulase was supplemented to a barley-based diet, the ATTD of CP and GE was increased. The use of exogenous enzymes to degrade indigestible dietary components has yielded inconsistent results mainly because of the presence of complex substrates in feedstuffs and the use of unsuitable enzyme activities for effective hydrolysis of such components (Slominski 2000). In addition, effect of enzyme supplementation improving nutrient digestibility tends to be low when diets contained highly digestible ingredients (Johnson *et al.* 1993). It may indicate that better nutrient digestibility can be got in early growth phase in pigs or supply special enzymes to pigs based on the diet ingredients.

Fecal noxious gas emission: Fecal noxious gas emission such as NH₃-N, H₂S, and volatile fatty acid has become one of the major air pollution in modern concentrative pig production (van Breemen *et al.* 1982, Slanina 1994). Zhao *et al.* (2011) reported that fecal H₂S measured on d 5 and 7 was reduced in growing pigs fed diet contained 20 or 30% enzyme (protease, amylase, xylanase, cellulase and α -galactosidase) fermented corn, and acetic acid was lower in 20 or 30% enzyme fermented corn treatments on d 7. On the other hand, there was no difference in fecal H₂S, acetic acid, and NH₃ gas emission concentrations in growing pigs fed different percentage of enzyme (protease, amylase, xylanase, cellulase and α -galactosidase) fermented oat or wheat diets (Guo *et al.* 2011, Zhang *et al.* 2011). It agrees

Table 3. Effect of dietary enzyme complex supplementation on fecal noxious gas emission in growing pigs^{1,2,3}

Item (ppm)	Treatment			SEM ⁴	P-value	
	CON	EC1	EC2		CON vs. EC1 + EC2	EC1 vs. EC2
Ammonia						
d 1	19.5	18.0	17.4	0.8	0.057	0.528
d 3	40.6	39.1	38.3	1.0	0.108	0.542
d 5	62.0	60.2	59.4	1.3	0.175	0.680
d 7	53.2	52.1	51.0	1.2	0.276	0.509
Hydrogen sulfide						
d 1	0.9	0.8	0.8	0.1	0.264	0.549
d 3	4.5	4.2	3.9	0.3	0.145	0.475
d 5	9.4	9.3	9.0	0.6	0.711	0.671
d 7	8.5	8.3	8.2	0.5	0.711	0.920
Total mercaptans						
d 1	10.9	10.0	9.6	0.8	0.239	0.726
d 3	20.8	20.3	19.6	0.9	0.424	0.574
d 5	27.6	26.9	26.8	0.6	0.296	0.870
d 7	27.1	26.2	25.8	0.8	0.285	0.734
Acetic acid						
d 1	10.8	10.2	9.5	0.6	0.219	0.381
d 3	18.3	17.8	17.6	0.6	0.454	0.887
d 5	25.5	24.9	24.2	0.6	0.218	0.381
d 7	24.8	23.7	23.2	0.6	0.103	0.650

¹CON, basal diet; EC1, basal diet + 0.5 g/kg enzyme complex; and EC2, basal diet + 1.0 g/kg enzyme complex. ²Each mean represents 10 pens with 6 pigs (initial BW, 26.40 ± 2.29 kg) per pen. ³Samples were collected on d 42, after 1 d fermentation, fecal gas emissions were measured, then measured again at d 3, 5, and 7. ⁴SEM, standard error of mean.

with our study that enzyme complex supplementation did not affect fecal NH₃, H₂S, total mercaptans, and acetic acid emissions on d 1, 3, 5, and 7 compared with the CON treatment (Table 3). No effects were observed on NH₃, H₂S, total mercaptans, and acetic acid emissions between the enzyme complex supplementation treatments (0.05 or 0.10%). Additionally, Jo *et al.* (2012) demonstrated that the fecal ammonia-N concentrations was not affected by dietary supplementation of exogenous enzymes (β -mannanase, α -amylase, and protease) in growing pigs fed a corn-soybean diet, which supported the fact that there was no difference in NH₃ emission in our study as well. When dietary NSP is increased, more substrate enters the large intestine for microbial fermentation and promotes bacterial activity, which results in more N excreting via the feces in the form of bacterial protein and less via the urine in the form of urea (Zhao *et al.* 2013b). The conversion of urea to NH₃ is a rapid process in comparison with the proteolysis of bacterial protein. This shift in N excretion will lower the NH₃ emission. In addition, as urea N is a substrate for the enzyme urease found in the feces, which is associated with NH₃ emission from the slurry, by reducing urea N, less substrate is present in the slurry for NH₃ production (Canh *et al.* 1998a, b), NH₃ emission will be decreased. Dierick and Decuyper (1996) reported that exogenous NSP enzyme supplementation can effectively degrade viscous NSP leading to a reduction in the viscosity of the diet and enhanced nutrient utilization. In this study, enzyme complex supplementation increased the ATTD of nutrient, thus, less dietary NSP enters the large intestine

for microbial fermentation. It may explain why no difference was observed in fecal noxious gas emission at the present study. As diets in this study were based on corn, which has a quite low content of NSP, the results indicated that enzyme complex has effect on low NSP of corn based diet in growing pigs.

In conclusions, the addition of enzyme complex improved ATTD of DM, N and GE. However, adding enzyme complex to corn based diets neither improved growth performance nor decreased fecal noxious gas emissions in growing pigs. Future investigations are necessary to explore the effect of enzyme complex on those criteria in pigs fed different diets with various growth phases.

REFERENCES

- AOAC International. 2007. *Official Methods of Analysis*. 18th edn. Association of Official Analytical Chemists, Gaithersburg, MD.
- Adeola O and Cowieson A J. 2011. Board-invited review: opportunities and challenges in using exogenous enzymes to improve nonruminant animal production. *Journal of Animal Science* **89**: 3189–18.
- Canh T T, Aarnink A J A, Verstegen, M W A and Schrama J W. 1998a. Influence of dietary factors on the pH and ammonia emission of slurry from growing-finishing pigs. *Journal of Animal Scienc* **76**: 1123–30.
- Canh T T, Sutton A L, Aarnink A J A, Verstegen M W A, Schrama J W and Bakker G C M. 1998b. Dietary carbohydrates alter the fecal composition and pH and the ammonia emission from slurry of growing pigs. *Journal of Animal Scienc* **76**: 1887–95.

- Dierick N and Decuyper J. 1996. Enzymes and growth in pigs. *Principles of Pig Science*. pp. 169–195. (Eds) Cole D J A, Wiseman J and Varley M A. Nottingham University Press, Nottingham, UK.
- Emiola I A, Opapeju F O, Slominski B A and Nyachoti C M. 2009. Growth performance and nutrient digestibility in pigs fed wheat distillers dried grains with solubles-based diets supplemented with a multicarbohydrase enzyme. *Journal of Animal Science* **87**: 2315–22.
- Fenton T W and Fenton M. 1979. An improved method for chromic oxide determination in feed and feces. *Canadian Journal of Animal Science* **59**: 631–34.
- Grieshop C M, Reece D E and Fahey G C. 2001. Nonstarch polysaccharides and oligosaccharides in swine nutrition. *Swine Nutrition*. pp. 107–130. (Eds) Lewis A J and Southern L L. CRC Press, Boca Raton, FL.
- Guo X Y, Baek H Y and Kim I H. 2011. Effects of dietary enzyme fermented wheat on growth performance, nutrient digestibility, blood characteristics, and fecal noxious gas emission in growing pigs. *Journal of Animal Science* **89** (Suppl. 1): 203 (Abstr.).
- Johnson R, Williams P and Campbell R. 1993. Use of enzymes in pig production. *Enzymes in Animal Nutrition*. pp. 49–60. (Eds) Wenk C and Boessinger M E. Kartaue Ittingen, Switzerland.
- Jo J K, Ingale S L, Kim J S, Kim Y W, Kim K H, Lohakare J D, Lee J H and Chae B J. 2012. Effect of exogenous enzyme supplementation to corn and soybean meal based diets and complex diets on growth performance, Nutrient digestibility and blood metabolites in growing pigs. *Journal of Animal Science* **90**: 3041–48.
- Kim I H, Hancock J D, Hines R H and Kim C S. 1998. Effects of cellulase enzymes and bacterial feed additives on the nutritional value of sorghum grain for finishing pigs. *Asian-Australasian Journal of Animal Sciences* **11**: 70–76.
- Lindemann M D, Cornelius S G, el Kandelgy S M, Moser R L and Pettigrew J E. 1986. Effect of age, weaning and diet on digestive enzyme levels in the piglet. *Journal of Animal Science* **62**: 1298–1307.
- Li S, Sauer W C, Mosenthin R and Kerr B. 1993. The effect of cellulase supplementation to cereal-based diets on crude protein and energy digestibility for starter pigs. *Journal of Animal Science* **71** (Suppl. 1): 163 (Abstr.).
- NRC. 2012. Nutrient requirements of swine. 11th ed. National Academy Press, Washington, DC.
- Omogbenigun F O, Nyachoti C M and Slominski B A. 2004. Dietary supplementation with multienzyme preparations improves nutrient utilization and growth performance in weaned pigs. *Journal of Animal Science* **82**: 1053–61.
- Park J S, Kim I H, Hancock J D, Hines R H, Cobb C, Cao H, Hong J W and Kwon O S. 2003. Effects of amylase and cellulase supplementation in sorghum-based diets for finishing pigs. *Asian-Australasian Journal of Animal Sciences* **16**: 70–76.
- Petty L A, Carter S D, Senne B W and Shriver J A. 2002. Effects of beta-mannanase addition to corn-soybean meal diets on growth performance, carcass traits, and nutrient digestibility of weanling and growing-finishing pigs. *Journal of Animal Sciences* **80**: 1012–19.
- Slanina S. 1994. Forest dieback and ammonia-a typical Dutch problem. *Chemical International* **16**: 2–3.
- Slominski B A. 2000. A new generation of enzymes for animal feeds. *Proceedings of 21st Western Nutrition Conference*. Winnipeg, Manitoba, Canada.
- Thacker P A, Campbell G L and Groot Wassink J W D. 1988. The effect of beta-glucanase supplementation on the performance of pigs fed hullless barley. *Nutrition Reports International* **38**: 91–99.
- van Breemen N, Burrough P A, Velthorst E J, van Dobben H F, Toke de Wit, Ridder T B and Reijnders H F R. 1982. Soil acidification from atmospheric ammonium sulphate in forest canopy throughfall. *Nature* **299**: 548–50.
- Wang M Q, Xu Z R and Sun J Y. 2004. Effect of indica rice diets supplemented with exogenous enzyme on growth and digestion of pigs fed paddy-based diets. *Rice Science* **11**: 336–41.
- Wang M Q, Xu Z R, Sun J Y and Kim B G. 2008. Effects of enzyme supplementation on growth, intestinal content viscosity, and digestive enzyme activities in growing pigs fed rough rice based diet. *Asian-Australasian Journal of Animal Sciences* **21**: 270–76.
- Yin Y L, McEvoy J D G, Schulze H, Henning U, Souffrant W B and McCracken K J. 2000. Apparent digestibility (ileal and overall) of nutrients and endogenous nitrogen losses in growing pigs fed wheat (var. Soissons) or its by-products without or with xylanase supplementation. *Livestock Production Science* **4**: 119–32.
- Yi J Q, Piao X S, Li Z C, Zhang H Y, Chen Y, Li Q Y, Liu J D, Zhang Q, Ru Y J and Dong B. 2013. The effects of enzyme complex on performance, intestinal health and nutrient digestibility of weaned pigs. *Asian-Australasian Journal of Animal Sciences* **26**: 1181–88.
- Yoon S Y, Yang Y X, Shinde P L, Choi J Y, Kim J S, Kim Y W, Yun K, Jo K, Lee J H, Ohh S J, Kwon I K and Chae B J. 2010. Effects of mannanase and distillers dried grain with solubles on growth performance, nutrient digestibility, and carcass characteristics of grower-ûnisher pigs. *Journal of Animal Science* **88**: 181–91.
- Zhang S, Lee J M and Kim I H. 2011. Effects of enzyme fermented oat on growth performance, digestibility, blood profile, and fecal gas emission of growing pigs. *Journal of Animal Science* **89** (Suppl. 1): 205 (Abstr.).
- Zhao P Y, Kim S C and Kim I H. 2011. The effect of enzyme fermented corn on growth performance, nutrient digestibility, blood profile, and fecal gas emission in growing pigs. *Journal of Animal Science* **89** (Suppl. 1): 204 (Abstr.).
- Zhao P Y, Wang J P and Kim I H. 2013a. Evaluation of dietary fructan supplementation on growth performance, nutrient digestibility, meat quality, fecal microbial flora, and fecal noxious gas emission in finishing pigs. *Journal of Animal Science* **91**: 5280–86.
- Zhao P Y, Wang J P and Kim I H. 2013b. Effect of dietary levan fructan supplementation on growth performance, meat quality, relative organ weight, cecal microflora, and excreta noxious gas emission in broilers. *Journal of Animal Science* **91**: 5287–93.